CP measurements in Bs decays to charm

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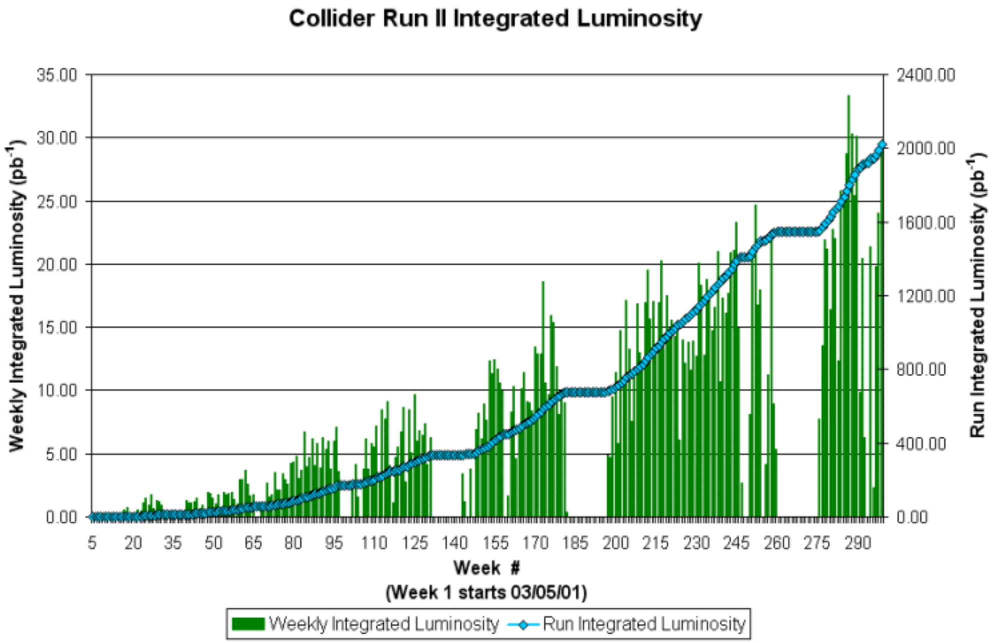
Plan

- Introduction
  - B-physics at Tevatron
  - CDF-II detector
- Towards the measurement of angle $\gamma(\Phi_3)$
  - CKM Matrix and angle γ
  - GLW Method
  - Measurement of $BR(B^- \to D^0K^-)/BR(B^- \to D^0\pi^-)$
- Towards the measurement of $\Delta\Gamma/\Gamma$
  - Motivation
  - Mehodology
  - Measurement of $BR(B_s \to D_s^+D_s^-)/BR(B^0 \to D_s^+D^-)$
- Conclusion and summary

B-physics at Tevatron

World Highest Energy Collider



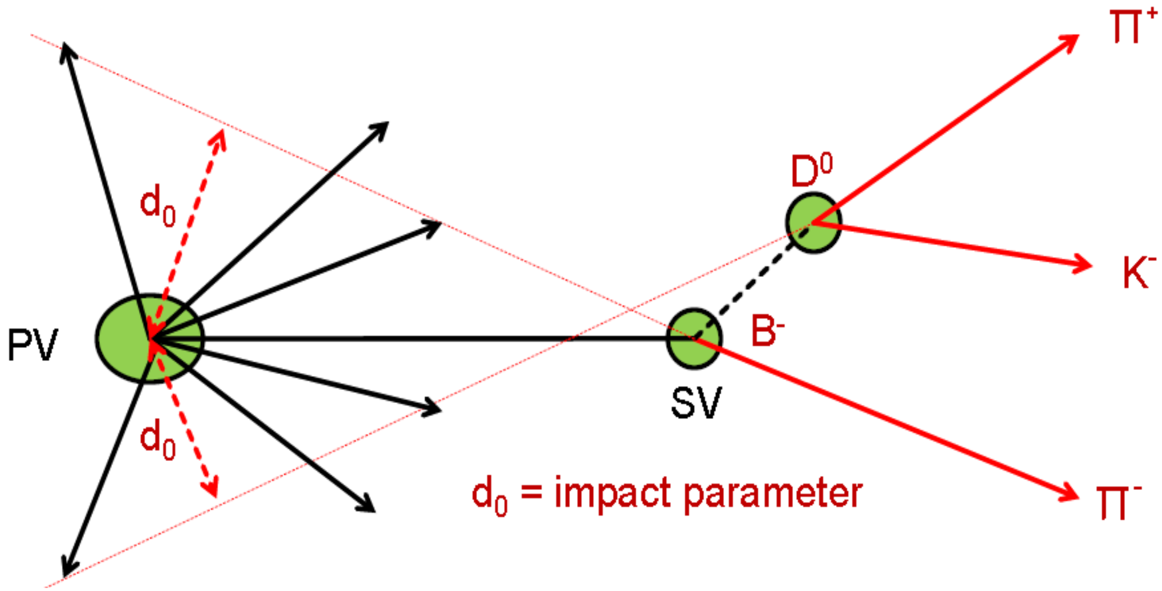
RUN II started in 2001:

- $\sqrt{s}$=1.96 TeV
- Record luminosity:
  L = 237.0 ×10^{30}cm^{-2}s^{-1}
- Delivered: $\int$Ldt ≈ 2.0 fb^{-1}

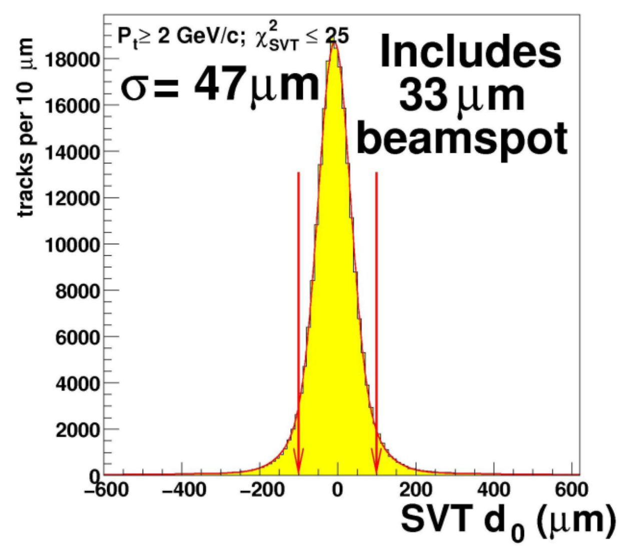
- Tevatron is a source of all B-hadron species: B_d, B_u, B_c, B_s, Λ_b, Σ_b .....
- $\sigma_b = 29.4 \pm 0.6 \pm 6.2\ \mu b$ ($|\eta| < 1$) at CDF
- Huge cross-section compared to B-factories but proportionally large backgrounds (≈ 10^3)
- Events have to be selected with specific triggers

Displaced track trigger

Silicon Vertex Trigger (SVT) :



Applied at L2 in a cascade of three level trigger system



Hadronic B trigger:

at least two tracks with

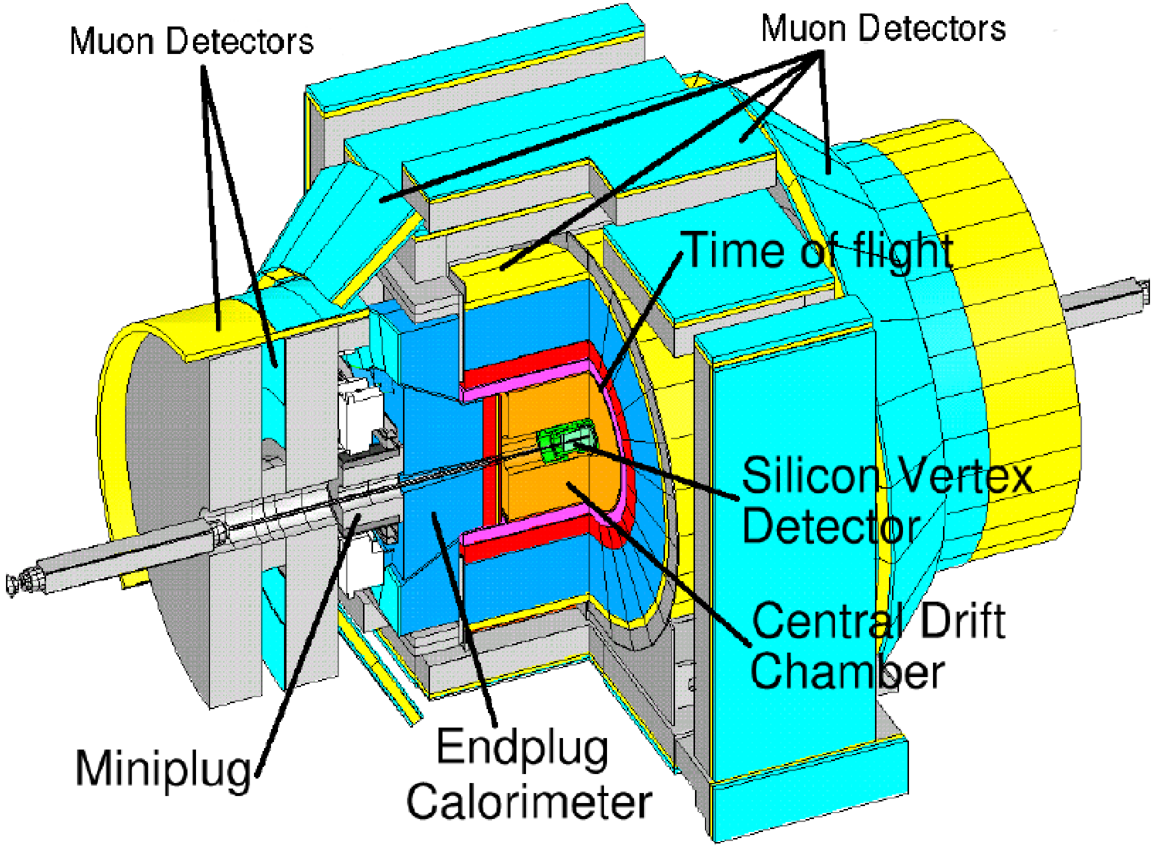
- $p_T > 2$ GeV
- 120 μm < $|d_0|$ < 1 mm
-

CDF-II detector

CDF II Detector:

multi-purpose detector

- excellent momentum resolution $\sigma(p)/p<0.1\%$
- Vertex resolution:
  - SVXII, L00
- Particle Identification:
  - TOF, dE/dx in COT



CKM Matrix and angle γ

The CKM matrix:

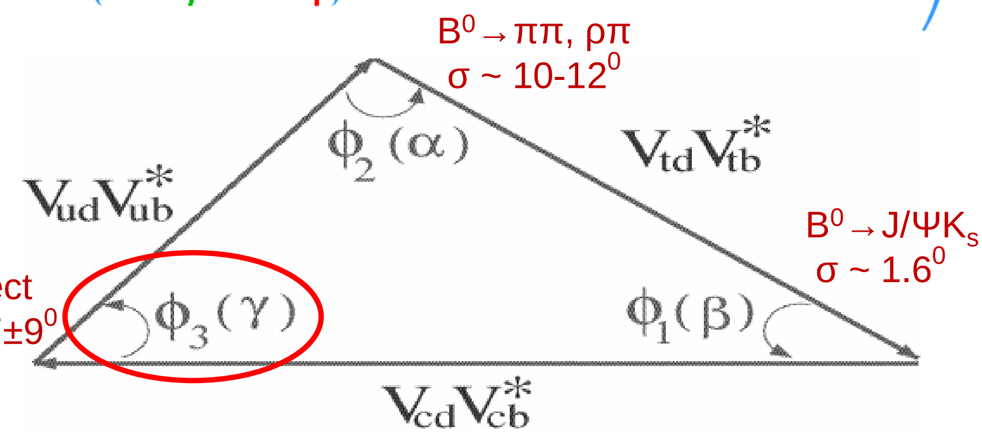
Wolfenstein parametrization: $\lambda = 0.2272 \pm 0.0010$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

The orthogonality condition between 1st and 3rd column:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

Expect $\sim 57 \pm 9^0$



Test SM: measure all sides and angles and check the consistency

A very naïve cross check:

$\alpha\,(\Phi_2) + \beta\,(\Phi_1) + \gamma\,(\Phi_3) = 2\pi$

Methods to measure γ

Several ways to measure Φ_3 depending on D^0 decay mode

- GLW Method : flav + CP
- ADS Method : flav + DCS
- Dalitz Method : $K_s^0\pi^+\pi^-$

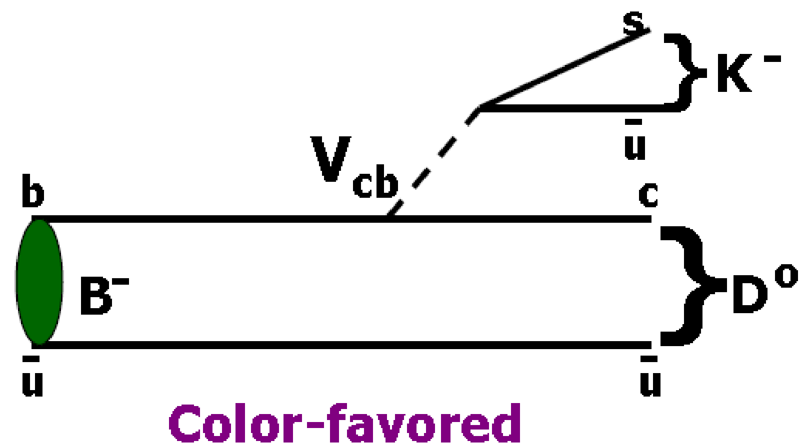
Consider: $B^- \rightarrow D_{CP}K^-$

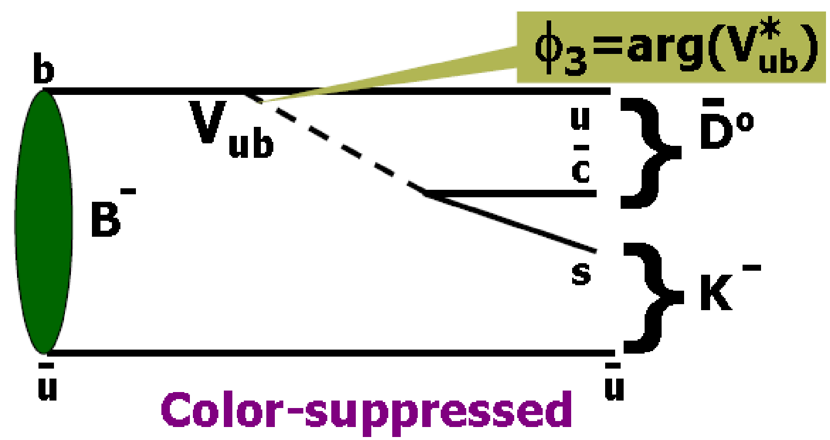
with $D_{CP} = 1/\sqrt{2}(D^0 \pm \bar{D}^0)$

Example D_{CP} :

CP even: K^+K^-, $\pi^+\pi^-$

CP odd : $K_s\pi^0$, $K_s\Phi$, $K_s\omega$, $K_s\rho^0$





GLW Method

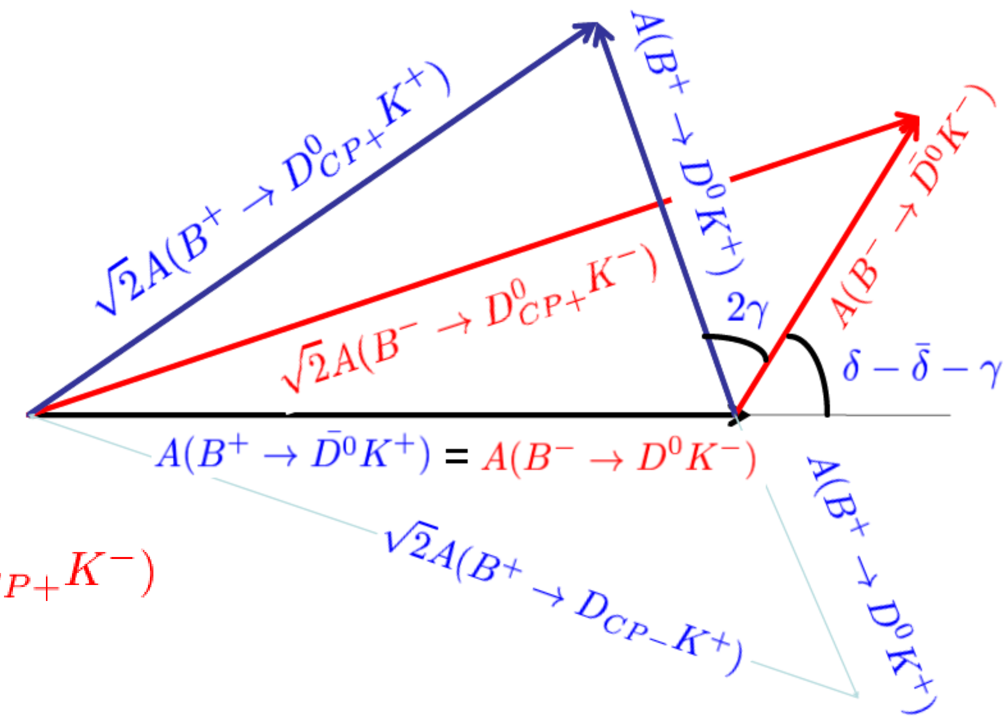
$B^\pm \to D^0_{CP\pm} K^\pm$ where $D^0_{CP\pm} = (D^0 \pm \bar{D}^0)/\sqrt{2}$

PLB 253 (1991) 483
PLB 265 (1991) 172

$$\sqrt{2}A(B^- \to D^0_{CP+}K^-) = A(B^- \to \bar{D}^0 K^-) + A(B^- \to D^0 K^-) = |A|e^{-i\gamma}e^{i\delta} + |\bar{A}|e^{i\bar{\delta}}$$

$$\sqrt{2}A(B^+ \to D^0_{CP+}K^+) = A(B^+ \to D^0 K^+) + A(B^+ \to \bar{D}^0 K^+) = |A|e^{i\gamma}e^{i\delta} + |\bar{A}|e^{i\bar{\delta}}$$

Construct two triangles from above six processes which give one of the solutions for γ



Note:

$A(B^+ \to \bar{D}^0 K^+)$ = $A(B^- \to D^0 K^-)$

> No CP violation

$A(B^+ \to D^0_{CP+}K^+)$ ≠ $A(B^- \to D^0_{CP+}K^-)$

> CP violated

GLW Method (cont…)

- But Interference between

$B^- \to D^0 K^- \to (K^+\pi^-)K^-$

and

$B^- \to \overline{D}^0 K^- \to (K^+\pi^-)K^-$

ADS Method
PRD 63 036005
PRL 78 3257
Stat limited

- Solution: M. Gronau, PRD 58, 037301

$$BR(B^- \to D^0_{CP} K^-) \neq BR(B^+ \to D^0_{CP} K^+)$$

- Instead measure:

$$R = \frac{BR(B^+ \to \overline{D}^0_{flav} K^+)}{BR(B^+ \to \overline{D}^0_{flav} \pi^+)}$$

$$R_\pm = \frac{BR(B^- \to D^0_{CP\pm} K^-) + BR(B^+ \to D^0_{CP\pm} K^+)}{BR(B^- \to D^0_{CP\pm} \pi^-) + BR(B^+ \to D^0_{CP\pm} \pi^+)}$$

$$A_{CP\pm} = \frac{BR(B^- \to D^0_{CP\pm} K^-) - BR(B^+ \to D^0_{CP\pm} K^+)}{BR(B^- \to D^0_{CP\pm} K^-) + BR(B^+ \to D^0_{CP\pm} K^+)}$$

- Use theoretical relations

$$R_{CP\pm} = 1 + r^2 \pm 2r \cos\delta \cos\gamma$$

$$A_{CP\pm} = \pm 2r \sin\delta \sin\gamma / R_{CP\pm}$$

where $R_{CP\pm} = R_\pm / R$

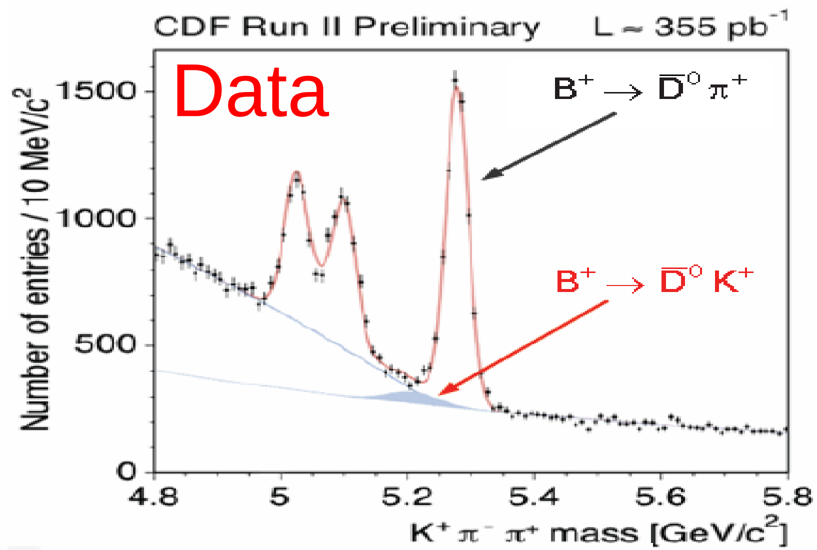
$$r = \frac{A(B^- \to \overline{D}^0 K^-)}{A(B^- \to D^0 K^-)} \sim 0.1\text{–}0.2$$

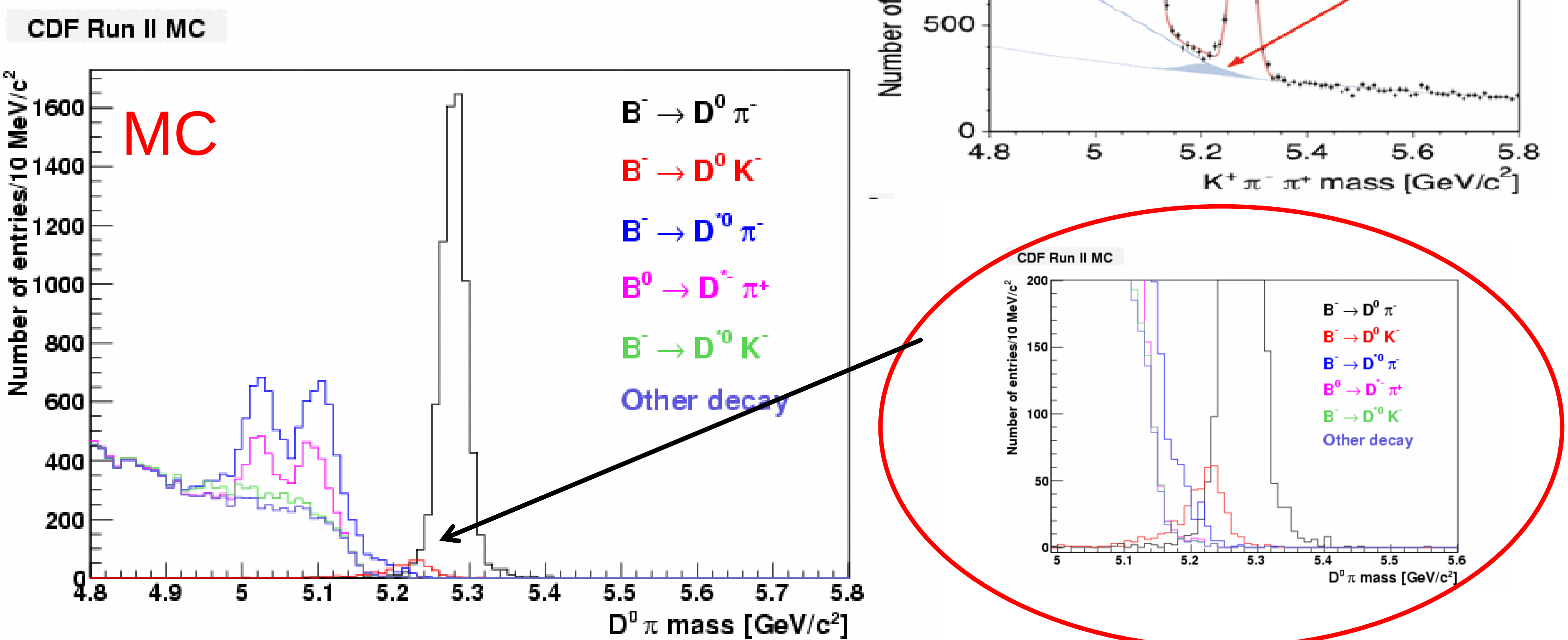
- $A_{CP+} R_{CP+} + A_{CP-} R_{CP-} = 0$

- This talk covers the measurement of R

Event reconstruction

- Analyzed 355 pb^{-1}
- Reconstruct $D^0 \to K^- \pi^+$
- Add another track with π -mass hypothesis to make B





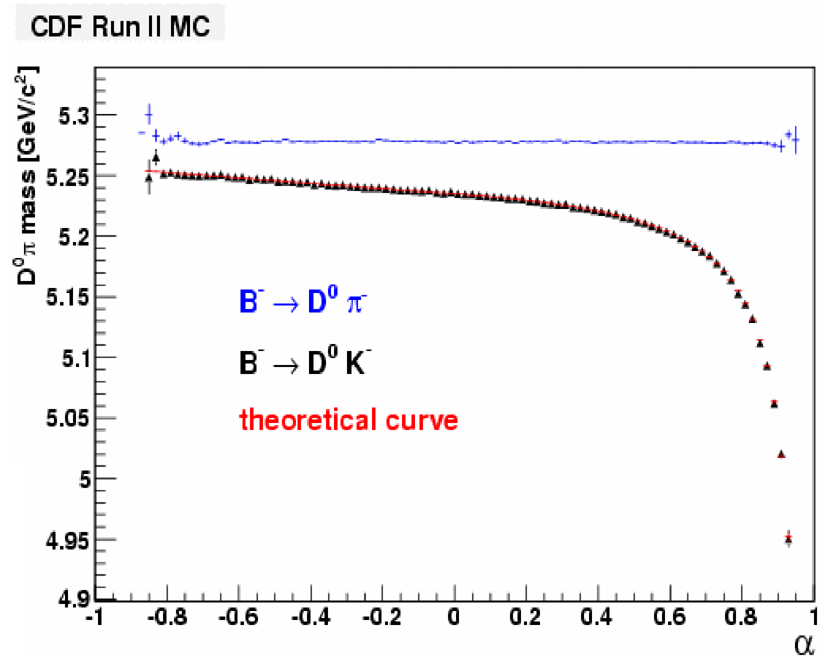
Likelihood fit

- Unbinned multidimentional likelihood fit, which combines kinematics and dE/dx information: $M_{D\pi}$, p_{tot}, PID and

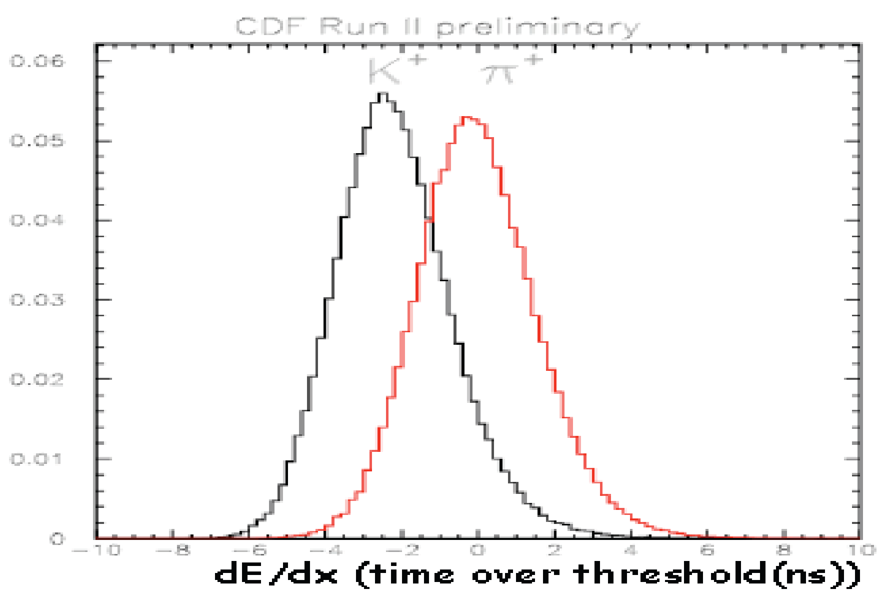
  where $\alpha = 1 - p_{tot}/p_D\ ;\ p_{tot} < p_D$

  $-(1 - p_D/p_{tot});\ p_{tot} \geq p_D$

- Fit mass window [5.17 – 5.60] GeV

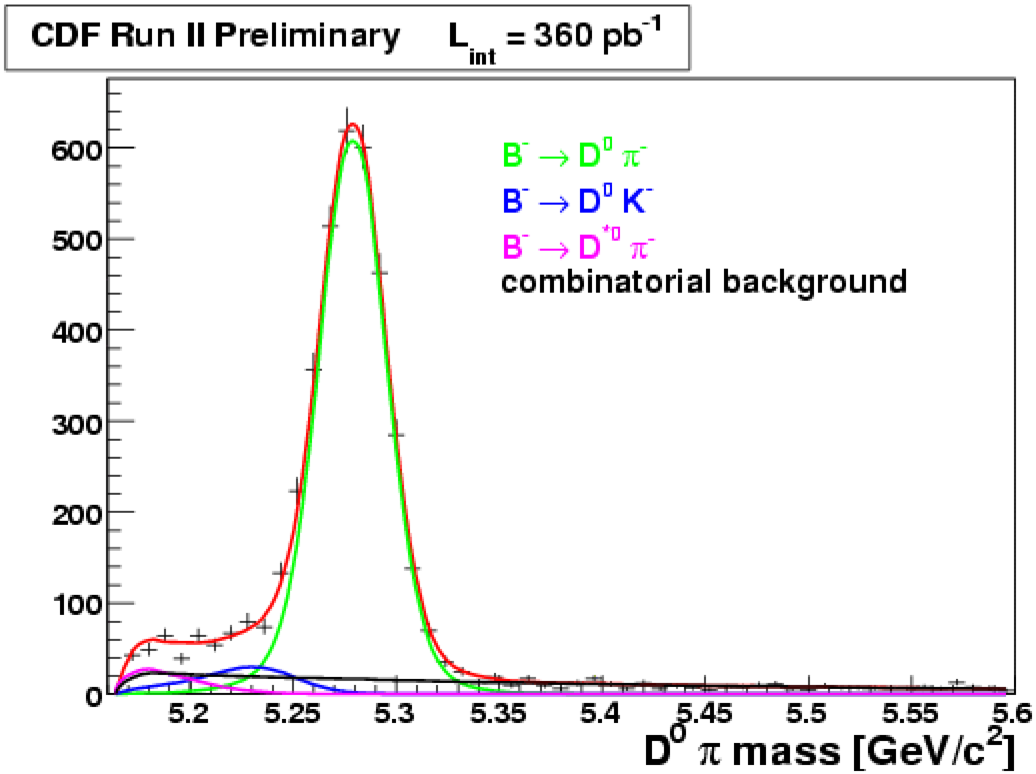


- α separates between $D^0\pi$ and D^0K modes



- Good K-π separation 1.4 σ for p_T > 2 GeV

Fit results

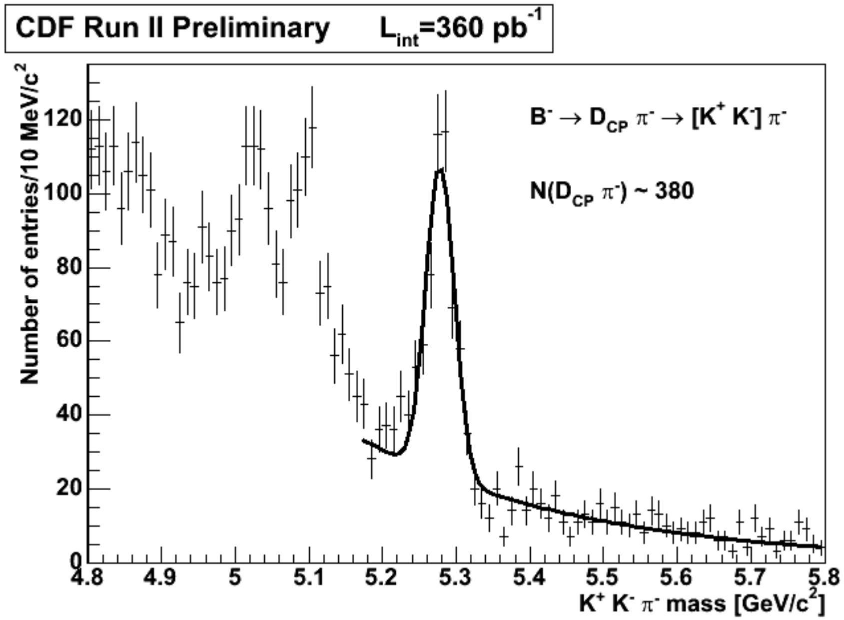


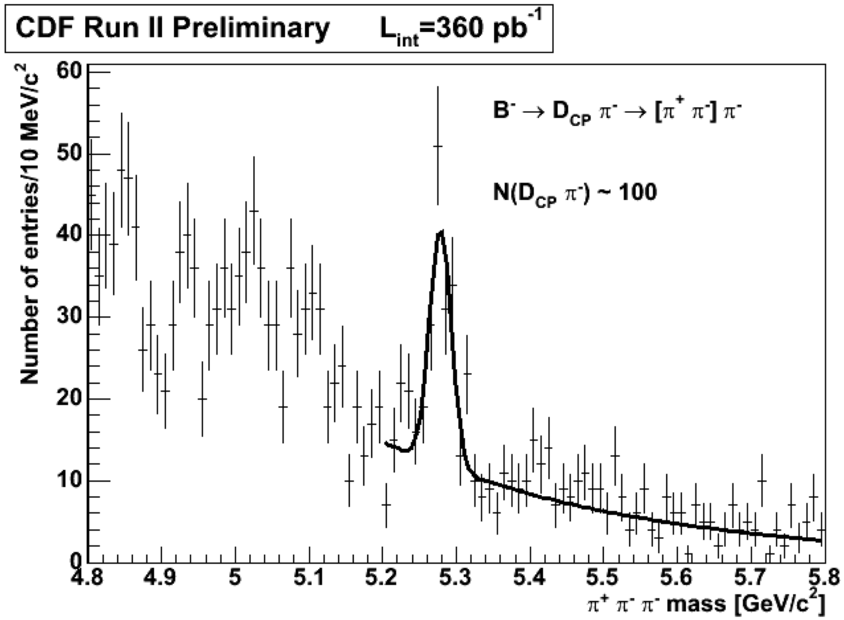
CDF Public Note: 8242

- N ($D^0\pi$) = 3265 ± 38
- N (D^0K) = 224 ± 22
- *For same yields, resolutions is same as B-factories !*

$$R = \frac{BR(B^+ \to D^0_{flav} K^+)}{BR(B^+ \to D^0_{flav} \pi^+)} = 0.065 \pm 0.007\,(stat) \pm 0.004\,(sys)$$

D_{CP} (KK, $\pi\pi$) Modes





- Analysis with 1 fb^{-1} is nearly complete
- Resolution expected for R_{CP} and A_{CP} would be comparable to the current resolution of B-factories

Bs → DsK Mode

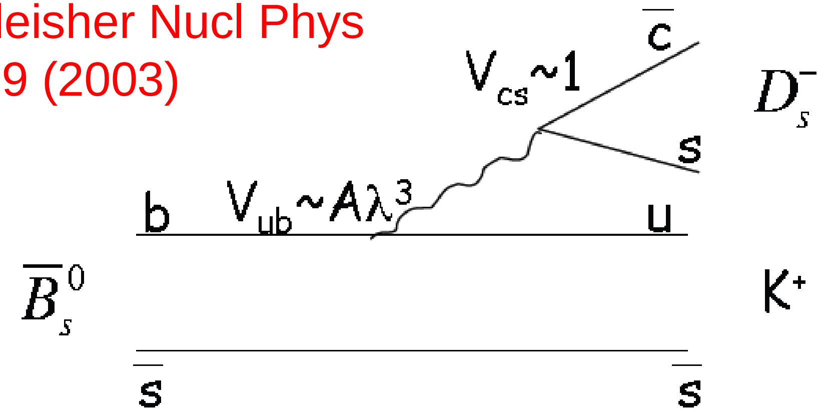
- Final states of both sign are accessible by both Bs mesons with similar sized amplitude

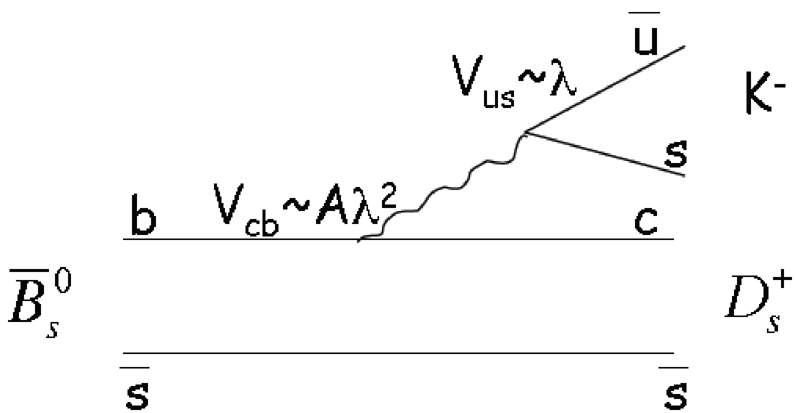
$$B_s^0 \rightarrow D_s^{\pm} K^{\mp}$$
$$\overline{B}_s^0 \rightarrow D_s^{\mp} K^{\pm}$$

- Bs oscillation is then cause the amplitude to interfere

- This is the cleanest channel to measure γ but time dependent CP asymmetry measurement is needed

R. Fleisher Nucl Phys B 659 (2003)





Expect ~ 200 events in 1 fb^{-1}

$$\frac{BR(B_s \to D_s^- D_s^+)}{BR(B^0 \to D_s^- D^+)}$$

Motivation

- Final goal is to measure BR($B_s \to D_s^{(*)+} D_s^{(*)-}$) to determine $\Delta\Gamma_s/\Gamma_s$
    - No time dependent analysis or tagging needed
- $B_s \to D_s^+ D_s^-$ is pure CP-even while $B_s \to D_s^{(*)+} D_s^{(*)-}$ is predominantly CP-even final state and gives the largest contribution to $\Delta\Gamma_s$:

I.Dunietz, R. Fleischer and U Nierste hep-ph/0012219

$$2BR(B_s \to D_s^{(*)} D_s^{(*)}) \approx \Delta\Gamma_{CP}/\Gamma$$
where $\Delta\Gamma_{CP} = \Delta\Gamma_s/\cos\Phi$

- BR($B^0 \to D_s^{(*)+} D^{(*)-}$) could be used to measure CP phase γ

hep-ph/0410015

Methodology

- Measure BR normalized to a more abundant channel with same topology as the signal
- Reconstruct multiple final state:
  - Normalized channel: $B^0 \to D_s^+ D^-$
    - $D^- \to K^+\pi^-\pi^-$
    - $D_s^+ \to \Phi\pi^+ (\Phi \to K^+K^-)$, $K^{*0}K^+ (K^{*0} \to K^+\pi^-)$, $\pi^-\pi^+\pi^+$
  - Signal channel: $B_s \to D_s^+ D_s^-$
    - First $D_s^+ \to \Phi\pi^+$ with $\Phi \to K^+K^-$
    - Other $D_s^- \to \Phi\pi^-$, $K^{*0}K^- (K^{*0} \to K^+\pi^-)$, $\pi^+\pi^-\pi^-$
- Yield determination: By fitting invariant mass
  - Get templates from MC for physics background
  - Float fractions with fixed shapes
- Estimate relative reconstruction efficiency from MC and use PDG values to calculate the branching fraction ratio

Normalized modes

- Measure BRs on other modes with similar topology to test the tools

  ▸ $B^0 \to D_s^+ D^-$ mode:

$$\frac{BR(B^0 \to D_s^+ D^-)}{BR(B^0 \to D^- 3\pi)} = 1.99 \pm 0.13(stat.) \pm 0.46(syst.)$$

[PDG 2005: 1.0 ± 0.5]

  ▸ $B^0 \to D_s^{(*)} D^{(*)}$ modes:

$$\frac{BR(B^0 \to D_s^{*-} D^+)}{BR(B^0 \to D_s^+ D^-)} = 0.9 \pm 0.2(stat.) \pm 0.1(syst.)$$

[PDG 2005: 1.3 ± 0.6]

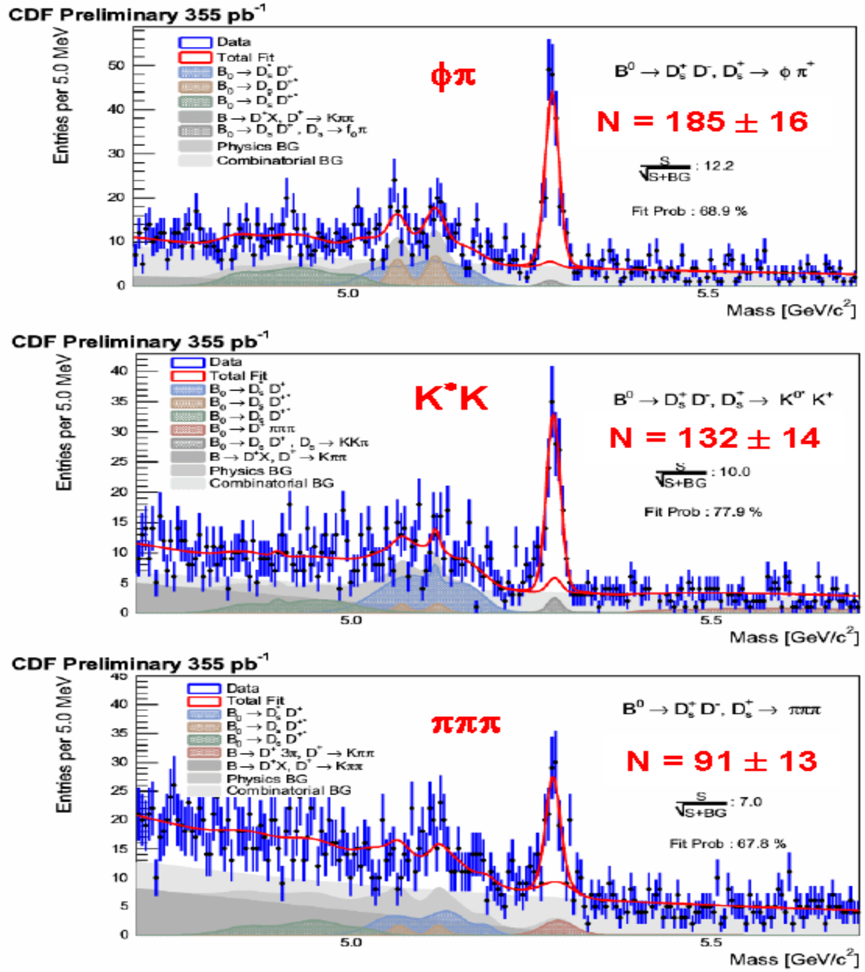
$$\frac{BR(B^0 \to D_s^- D^{*+})}{BR(B^0 \to D_s^+ D^-)} = 1.5 \pm 0.5(stat.) \pm 0.1(syst.)$$

[PDG 2005: 1.3 ± 0.6]

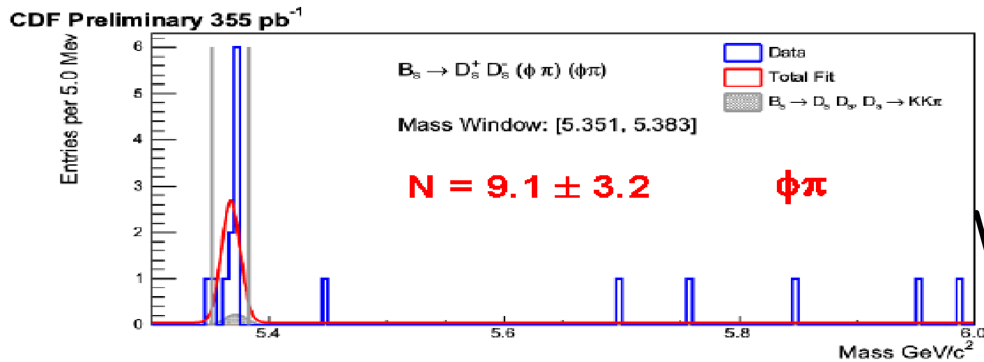
$$\frac{BR(B^0 \to D_s^{*-} D^{*+})}{BR(B^0 \to D_s^+ D^-)} = 2.6 \pm 0.5(stat.) \pm 0.2(syst.)$$

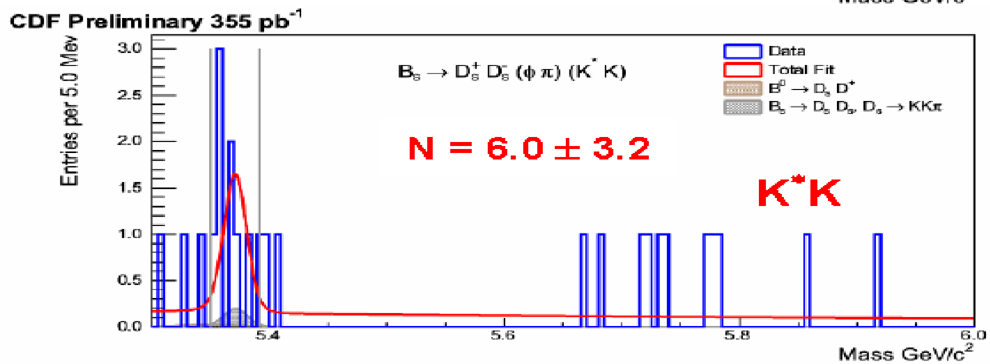
[PDG 2005: 2.4 ± 1.1]

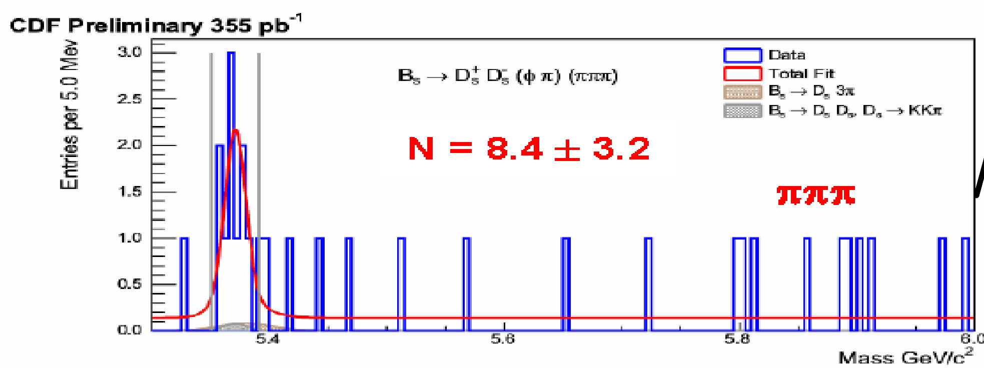
Normalized modes



Signal modes

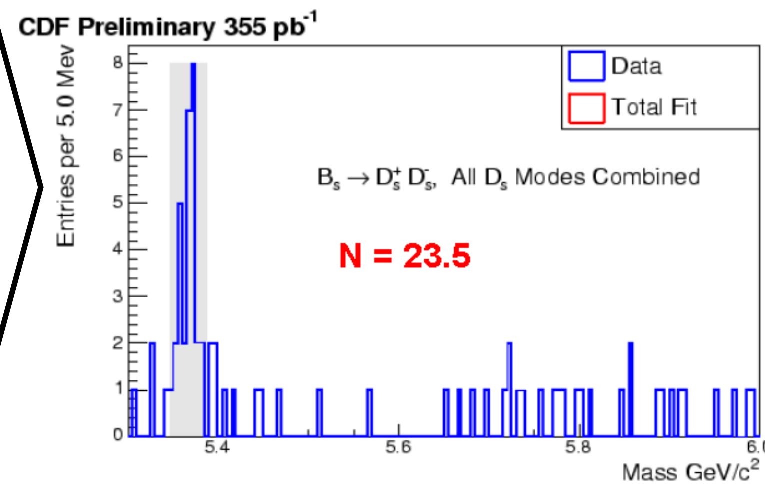






Observation of Bs → DsDs

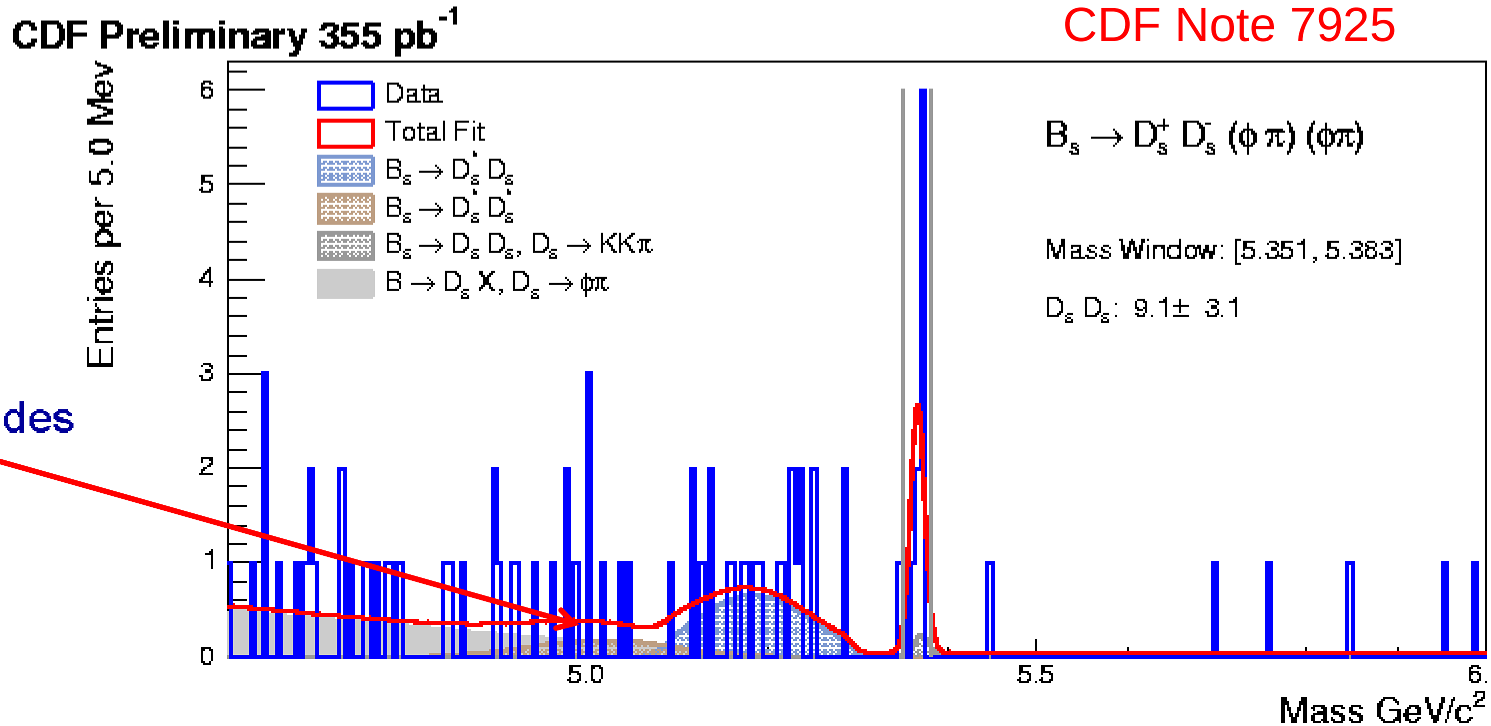
For both Ds→ Φπ:
Observed 9.1 ± 3.2 candidates
corresponding to 6.7σ



Total of 23.5 candidates
all three decay modes

BR results

CDF Note 7925



$B_s \to D_s^{(*)} D_s^{(*)}$ modes

$$\frac{BR(B_s \to D_s^- D_s^+)}{BR(B^0 \to D_s^- D^+)} =$$

$$1.67 \pm 0.41\ (\text{stat}) \pm 0.12\ (\text{syst}) \pm 0.24\ (f_s/f_d) \pm 0.39\ (\text{Br})$$

World first measurement !!

Conclusion and summary

- We have measured

$$R = \frac{BR(B^+ \to D^0_{flav}\, K^+)}{BR(B^+ \to D^0_{flav}\, \pi^+)} = 0.065 \pm 0.007\,(stat) \pm 0.004\,(sys)$$

  - This is the first step towards γ measurement
  - Analysis with 1 fb^{-1} is near complete and expect same resolution on R_{CP} and A_{CP} compared to B-factories

- Observation of $B_s \to D_s D_s$ mode and measured

$$\frac{BR(B_s \to D_s^- D_s^+)}{BR(B^0 \to D_s^- D^+)} = 1.67 \pm 0.41\,(stat) \pm 0.12\,(syst) \pm 0.24\,(f_s/f_d) \pm 0.39\,(BR)$$

- World first measurement !!

- Analysis with 1 fb^{-1} coming soon ! Stay tune!

BACK UP

Systematics

dE/dx	0.0015
Combinatorial background	0.001
Mass resolution tails	0.0006
Input mass	0.001
$D^{*0}\pi$ (1)	0.003
$D^{*0}\pi$ (2)	0.001
MC statistics	0.002
Total	0.004

Systematics

Effect	Syst. Uncertainty [%]
B-meson spectrum	$\pm 3.0\%$
B_s lifetime	$\pm 2.0\%$
$D_s \to \pi\pi\pi$ composition	$\pm 3.0\%$
$B^0 \to D_s D^+(\phi\pi)$ Fit	$\pm 2.3\%$
$B^0 \to D_s D^+(K^* K)$ Fit	$\pm 4.2\%$
$B^0 \to D_s D^+(\pi\pi\pi)$ Fit	$\pm 8.4\%$
$B_s \to D_s^- D_s^+(\phi\pi)$ Fit	$\pm 6.3\%$
$B_s \to D_s^- D_s^+(K^* K)$ Fit	$\pm 8.5\%$
$B_s \to D_s^- D_s^+(\pi\pi\pi)$ Fit	$\pm 4.1\%$
$B^0 \to D_s^- D^+(\phi\pi)$ Cuts	$\pm 5.0\%$
$B_s \to D_s^- D_s^+(\phi\pi)$ Cuts	$\pm 5.0\%$
Common	$\pm 6.9\%$